WSRC-RP-89-81

CHLORINE DEMAND OF SAVANNAH RIVER WATER (u)

by

E. W. Wilde

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

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Derivative Classifier

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ABSTRACT

Savannah River water used for cooling SRS reactors was tested for chlorine demand and the rate of decay for both free and total residual chlorine on seven quarterly dates between 1986 and 1988. Test conditions included chlorine dosages of 1, 3, and 5 mg/L and a variety of contact times ranging from less than 1 minute to one day. Statistically significant differences were detected in the chlorine demand for the seven dates; however, there was no discernible seasonality to the variation. The chlorine demand, amount of combined residual chlorine formed and the persistence of total residual chlorine following a dose of 5 mg/L was significantly greater on one of the seven sampling dates (February, 1988) compared to all of the other dates. These differences could not be attributed to water temperature, pH, ammonia nitrogen concentration, or the amount of rainfall prior to or during the collection of the cooling water. Except as noted above, dissipation of chlorine was similar among the sampling dates. Most reactions of available chlorine with other constituents in the cooling water occurred in the first minute of contact, although measurable total chlorine residuals generally persisted for 24 hours after the dose had been administered. The results of this study indicate that, with occasional exceptions, a chlorine dose of between 3 and 5 mg/l will provide a free chlorine residual of 1 mg/L in Savannah River water.

INTRODUCTION

This report is a sequel to an earlier report (Wilde, 1986) providing baseline data in support of the preliminary design of antifouling measures for a cooling tower to dissipate heat from the K-Reactor cooling system. It describes the latest research from a variety of studies that have been conducted with regard to antifouling measures for the SRS reactor cooling water systems during the past few years (Hollod and Wilde, 1982; Pope, et.al., 1982; Wilde, et.al., 1983a&b; Mayack, et.al., 1984; Wilde, et.al., 1984; Soracco et.al., 1984 & 1985).

During the spring of 1986, personnel from the Environmental Sciences Section (ESS) of the Savannah River Laboratory (SRL) performed several experiments involving chlorination and dechlorination of Savannah River cooling water (Wilde, 1986). Chlorination of the influent to the cooling tower was deemed necessary to combat possible biofouling and dechlorination of the effluent from the tower was deemed necessary to meet expected future NPDES limits for residual chlorine discharges to the associated receiving stream.

The 1986 study results indicated that chlorine demand and decay rates were similar for three different sampling dates in the spring; however, it was recommended that additional tests be performed to assess seasonal variability in chlorine demand. Additional tests of chlorine demand and residual chlorine decay rates in Savannah River cooling water were subsequently conducted by SRL-ESS personnel at quarterly intervals for an additional six dates. The main purpose of the studies described in the present report are to provide background data for assessing the chlorination requirements of proposed cooling towers and other facilities where chlorination of Savannah River water is required.

METHODS AND MATERIALS

Field Procedures

Approximately 15 liters were collected from the K-Reactor cooling water outfall (NPDES Outfall K-011) on each of the following dates: May 16, 1986; October 13, 1986; January 12, 1987; April 6, 1987; July 20, 1987; October 12, 1987 and February 16, 1988. K-Reactor was operating on all dates except January 12, 1987. Water temperature was measured at the time of collection with a mercury thermometer. All water was collected in the morning to minimize the possibility that samples would contain residual chlorine associated with the routine chlorination of heat exchangers or SRS river pumphouses which was conducted on this once-through system in late afternoon and early evening during this study period.

Laboratory Procedures

Samples were processed the same way on each of the seven sampling dates. Eight one-liter subsamples from the 15-liter composite cooling water sample were placed in each of eight, 2-liter Erlenmeyer flasks. The flasks were placed in a walk-in cooler and cooled to room temperature (75°F - 80°F). While the samples were cooling, chlorine (laboratory grade NaOCl containing ca. 5% Cl_2) was added to flasks containing 1 liter of double distilled chlorine-demand-free water to determine the correct quantities of stock sodium hypochlorite (NaOCl) solution needed to supply preselected chlorine dosages of 1, 3, and 5 mg/L. Generally, quantities of 20 µl, 60 µl, and 100 µl of a stock solution of NaOCl, resulted in the desired chlorine residuals of 1 mg/l, 3 mg/l, and 5 mg/l. When the expected chlorine residuals did not occur in the chlorine-demand-free water following appropriate additions of stock NaOCl solution, the stock solution was replaced.

All residual chlorine measurements conducted as part of the study were made by the DPD method using Hach DR-100 test kits. The decision to use this technique was based on previous chlorine studies at the site (Wilde, 1986), in which a series of total residual chlorine (TRC) measurements made simultaneously by three methods revealed that the DPD method (Hach DR-100 kit) and the amperometric titration method produced statistically similar results while an ion-selective electrode method provided significantly lower values.

When the effluent cooling water samples that had been placed in the walk-in cooler had cooled to room temperature, the flasks were removed, covered with aluminum foil, labeled, and placed on magnetic stirrers. Stir bars were added. TRC and free residual chlorine (FRC) were measured in two of the flasks to determine "background" readings. In addition to residual chlorine measurements, subsamples from these two flasks were measured for ammonia nitrogen (Nessler method using a Hach DR 100 colorimeter)) and pH (using a pH meter).

A chlorine dose of 1 mg/l Cl_2 (determined by the chlorine additions to chlorine-demand-free distilled water described above) was added to each of a different pair of flasks containing the cooling water. Subsamples were withdrawn immediately and simultaneously from both flasks and FRC and TRC were measured using two Hach DR-100 kits. Additional subsamples were withdrawn from the two flasks at intervals of 10, 30, 60, 120, 240, and 1440 minutes (24 hr) and measured for FRC and TRC. The flasks were kept covered and stirred except for the brief periods when subsamples were withdrawn.

The same procedure as described above was repeated with different sets of replicate flasks dosed at 3 mg/l Cl_2 and 5 mg/l Cl_2.

Data Processing Procedures

Numerical results were computerized and the data were tabulated, graphed and statistically analyzed on a mainframe computer system using a group of software programs collectively called the Statistical Analysis System (SAS) (SAS Institute Inc., 1985). Statistical testing was principally conducted using the general linear model (GLM) procedure (SAS Institute Inc., 1988) which uses least squares to fit fixed-effects linear models to the data.

RESULTS AND DISCUSSION

All results of the TRC and FRC measurements made on the seven dates in conjunction with this study are reported in Appendix Table A-1. Temperature, pH, and ammonia nitrogen levels of the water on each collection date are shown in Appendix Table A-2.

Chlorine Demand

Chlorine demand is defined as the difference between the amount of chlorine added to the water and the amount of chlorine remaining at the end of a specified contact period (White, 1986). Although no universal standard exists for the amount of chlorination required for biofouling control, it has been reported (EPRI, 1984) that chlorine dosages ranging from 0 to 5 mg/L with contact times ranging from 0 to 120 minutes provide adequate control. Iron bacteria and algae are considered to be the most resistant micro-biofouling organisms (EPRI, 1984). Algae can generally be controlled with a minimum of 1.0 mg/l FRC and a one-hour contact time. However, in some cases, a contact time of two hours has reportedly been required to control algae in cooling tower applications (EPRI, 1984).

Chlorine demand varies with the amount of chlorine applied and the contact time (APHA, 1980). This is undoubtedly because available chlorine reacts with numerous organic and inorganic compounds at various reaction rates and many of the reaction rates (e.g. with biological materials) are influenced by the amount of residual chlorine present (White, 1986). In the present study, as the chlorine dosage was increased from 1, to 3, to 5 mg/L, the chlorine demand increased significantly (Table 1.)

Figure 1 shows the chlorine residual concentrations in K-Reactor cooling water that were measured on seven dates following three chlorine dosages and three contact periods. The data indicate chlorine demand was similar on all dates except the February 1988 date in which the chlorine demand, particularly for TRC, was substantially higher.

TABLE 1.

Chlorine Demand(mg/L) of K-Reactor Cooling Water With Three Dosages and Three Contact Periods on Seven Sampling Dates.

		5/16/86		10/13/86		1/12/87		4/06/87		7/20/87		10/12/87		2/16/88	
CL2 DOSE (mg/L)	CONTACT TIME (Minutes)	TRC	FRC	TRC	FRC	TRC	FRC	TRC	FRC	TRC	FRC	TRC	FRC	TRC	FRC
1	<1	0.47	0.59	0.52	0.90	0.45	0.92	0.46	0.91	0.68	0.94	0.61	0.87	0.83	0.97
1	10	0.48	0.74	0.55	0.95	0.47	0.88	0.48	0.91	0.70	0.94	0.63	0.92	0.88	0.96
1	30	0.50	0.94	0.54	0.82	0.53	0.89	0.52	0.97	0.74	0.97	0.65	0.93	0.88	0.94
3	<1	1.13	1.89	1.52	2.21	1.38	2.53	1.30	2.00	1.60	2.01	1.60	2.19	2.26	2.94
3	10	1.94	2.63	2.02	2.73	2.00	2.49	1.90	2.78	2.14	2.49	2.14	2.54	2.30	2.90
3	30	2.39	2.76	2.10	2.89	2.08	2.90	1.88	2.75	2.51	2.85	2.54	2.87	2.33	2.94
5	<1	1.83	2.10	2.60	3.20	1.85	2.58	2.35	3.10	2.50	2.80	2.58	2.95	3.76	4.79
5	10	2.43	2.80	3.71	4.23	3.23	3.70	3.10	3.65	2.80	3.15	3.25	3.55	4.03	4.86
5	30	2.75	3.00	4.11	4.42	3.65	3.95	3.73	4.09	3.35	3.60	3.55	3.86	4.10	4.91

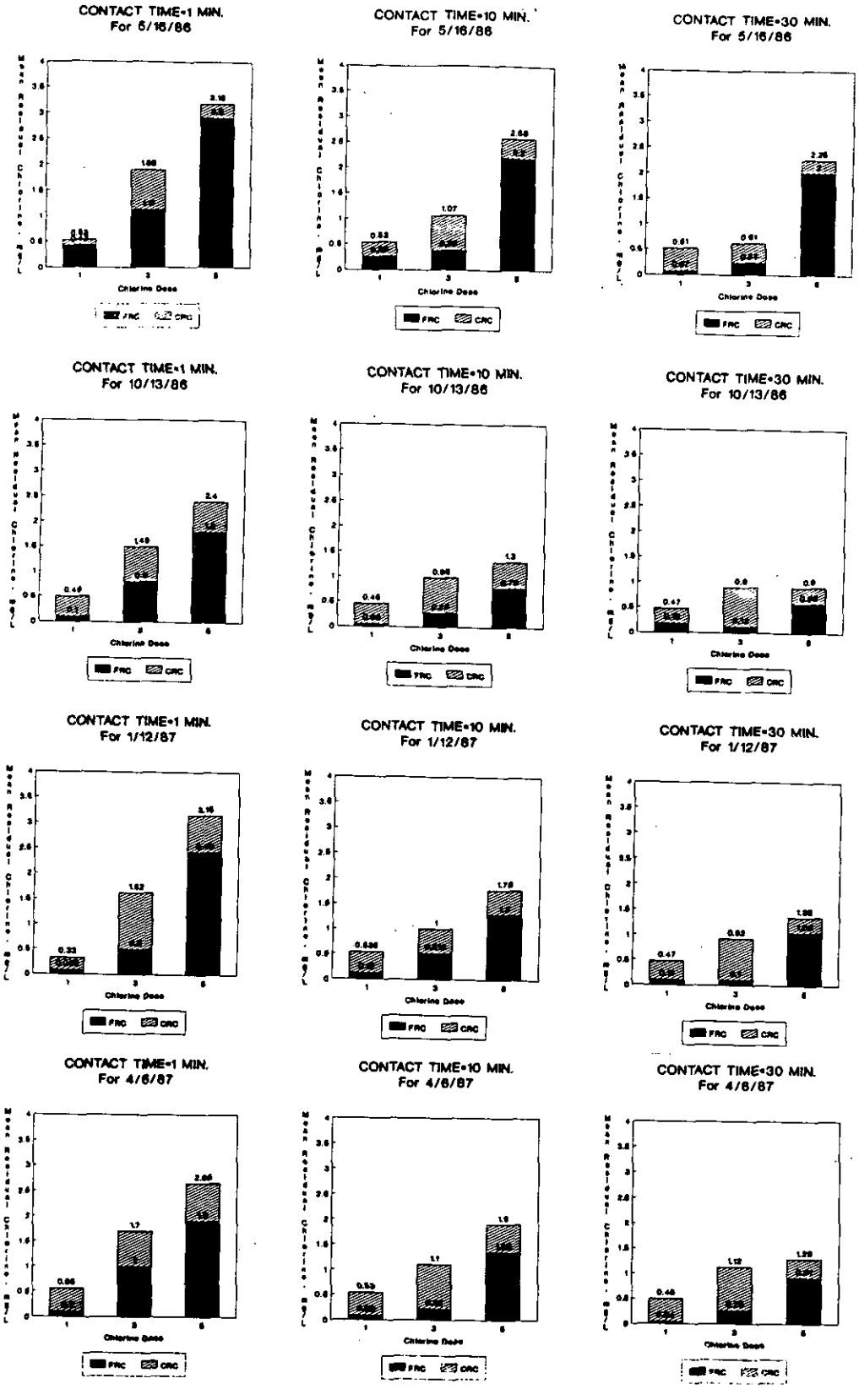

FIGURE 1. Total, Free, and Combined Chlorine Residual Concentrations in K-Reactor Cooling Water Following Three Dosages and Three Contact Periods on Seven Sampling Dates

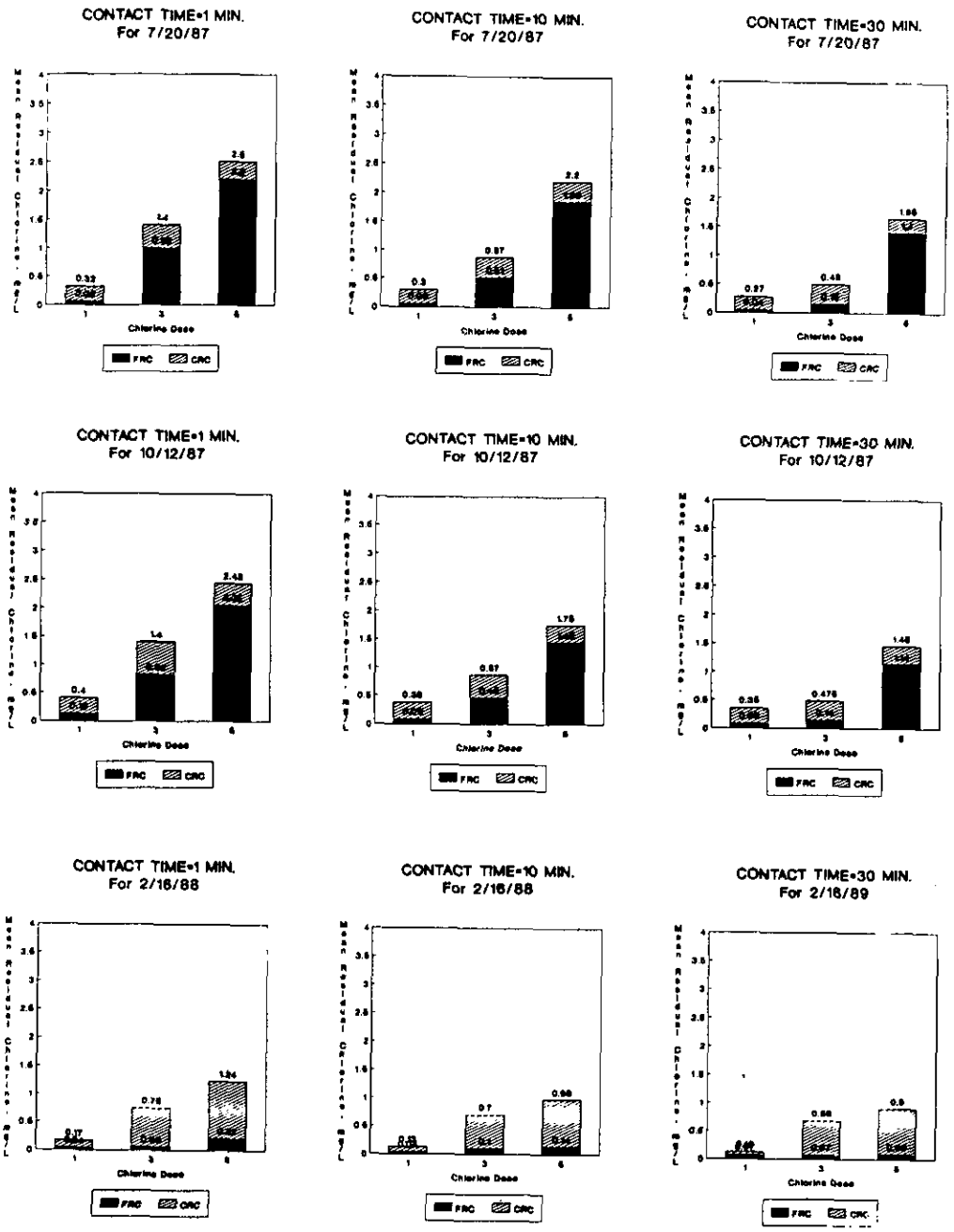

FIGURE 1, contd

Statistical comparisons (ANOVA) revealed significant differences between dates for TRC demand, FRC demand, and the amount of combined residual chlorine formed. The February 16, 1988 sampling date had significantly higher ($P = <0.05$) values for all of these parameters in many of the comparisons. When the data were grouped by season and statistically analyzed (GLM procedure), significant differences ($P = <0.05$) were rarely detected between the four seasons for any combination of dose, contact time and type of residual chlorine. Thus, no predictable seasonal influence on chlorine demand of Savannah River water was evident.

The significant differences between the chlorine residuals measured on the February 1988 and the other dates could not be attributed to water temperature, pH, or the ammonia level (Appendix Table 2). Thus, meteorological records maintained by the SRL Environmental Transport Section were examined to see if rainfall prior to or during the sampling periods was correlated with chlorine demand. Table 2 compares rainfall for a six day period before and during each sampling date with the mean chlorine demand for three dosages and contact times. Linear regression analysis revealed no meaningful relationship between rainfall prior to and during the sampling date and the chlorine demand for free or total residual chlorine. Correlation coefficients (r values) were -0.11 for both TRC and FRC in relation to rainfall.

The results of this study show that the specific chlorine dosage required to obtain an FRC of 1 mg/l in K- Reactor cooling water is variable and unpredictable. It appears that, in general, a dose of between 3 mg/L and 5 mg/L will be sufficient (Figure 1). However, during conditions such as those that existed on the February 16, 1988 sampling date of the present study, a dosage of well above 5 mg/L will be required.

Chlorine dissipation rates

TRC concentrations in K-Reactor cooling water at various time intervals on seven dates following the injection of a specific chlorine dose are presented in Figures 2 and 3. The data clearly show that most of the reactions of K-Reactor cooling water and residual chlorine occur within the first minute of contact, although some residual chlorine generally persisted in the flasks after mixing for 24 hours.

TRC concentrations and dissipation rates did not vary in a consistent way between dates (i.e for all three dosages examined). However, with a 5 mg/L dose, the February 16, 1988 samples contained substantially more TRC than was the case on any of the other sampling dates. There was no apparent seasonal pattern in dissipation rates.

TABLE 2.

Rainfall in relation to chlorine demand of Savannah River water collected at the K-Reactor cooling water outfall on seven dates

DATES	PRECIPITATION*	MEAN TRC DEMAND**	MEAN FRC DEMAND**
May 11-16, 1986	1.41	1.54	1.94
Oct. 8-13, 1986	2.37	2.01	2.48
Jan. 7-12, 1987	0.09	1.73	2.31
Apr. 1-6, 1987	0.20	1.74	2.35
Aug. 15-20, 1987	0.00	1.89	2.19
Oct. 7-12, 1987	0.00	1.94	2.29
Feb. 11-16, 1988	0.18	2.37	2.91

*Accumulative total inches for each sampling date and the five days preceding the sampling date

**Average value for dosages of 1, 3, and 5 mg/L and contact times of <1, 10, and 30 minutes

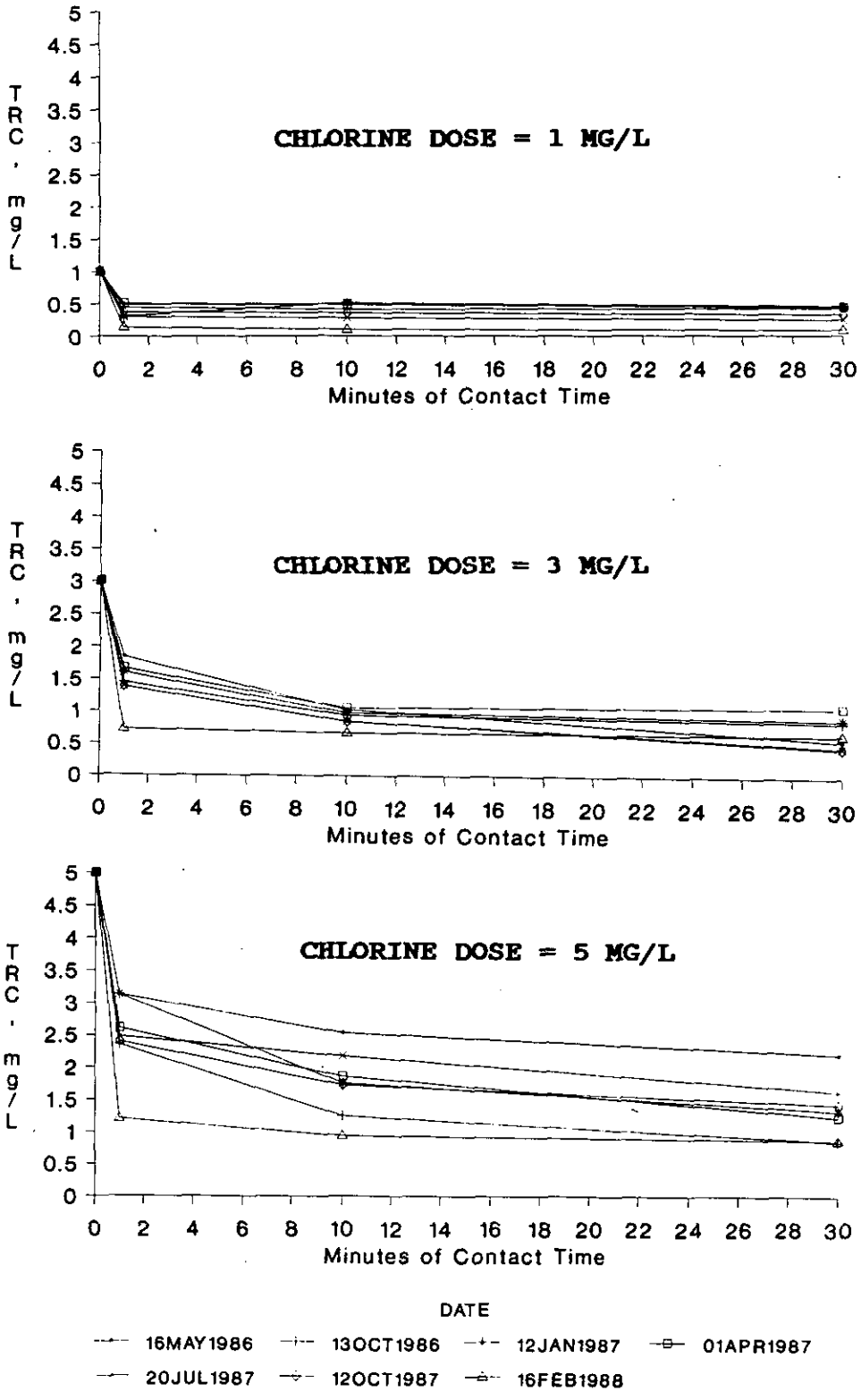

FIGURE 2. Dissipation of Total Residual Chlorine in Savannah River Water during A 30-minute time period following the addition of three chlorine doses on seven sampling dates

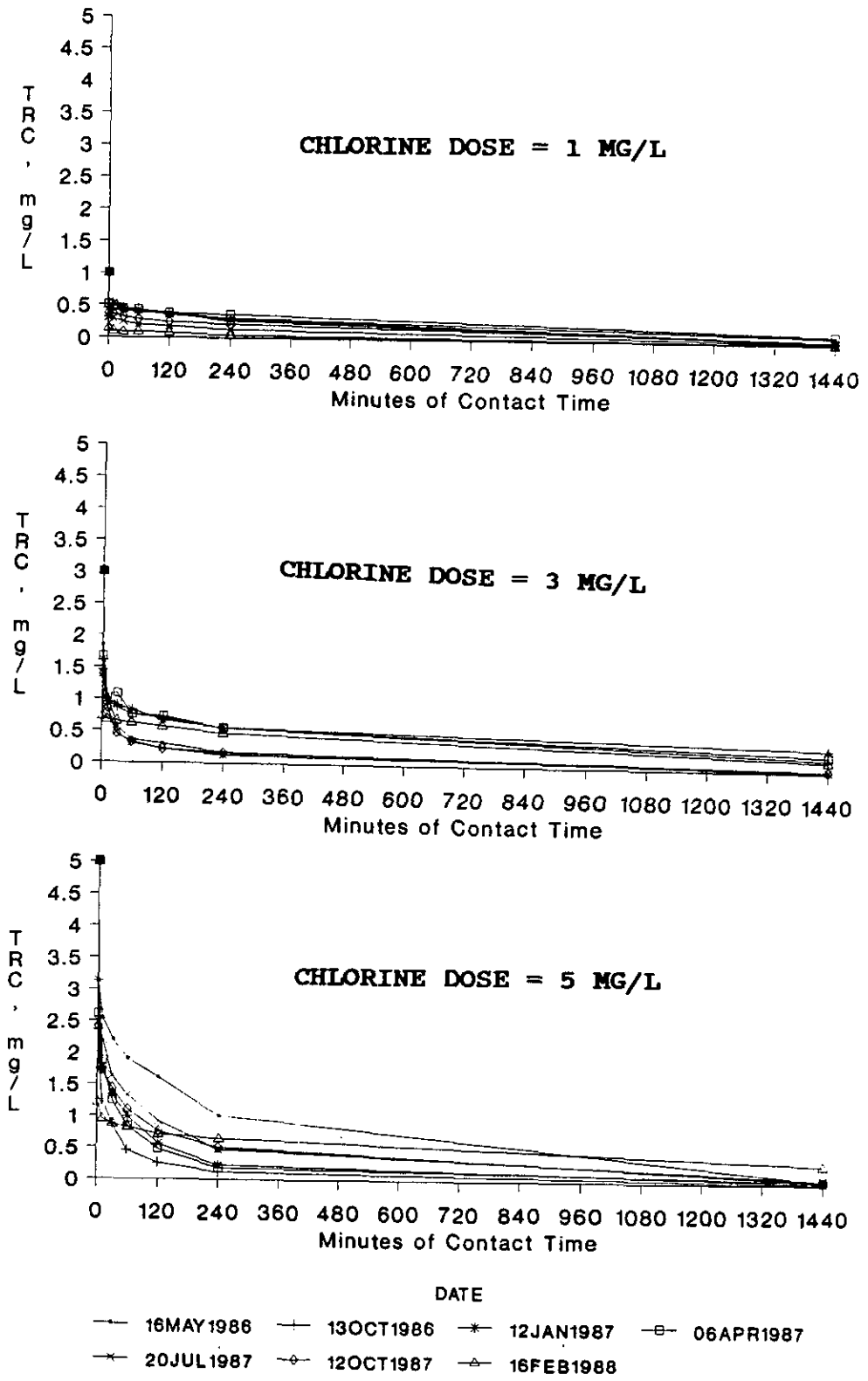

FIGURE 3. Dissipation of Total Residual Chlorine in Savannah River Water during A 24-hour (1440 min) time period following the addition of three chlorine doses on seven sampling dates

The higher chlorine demand, greater amount of combined chlorine formed, and longer persistence of TRC in the samples collected on February 16, 1988 compared to samples collected on six other sampling dates could not be explained by differences in water temperature (all testing was done at room temperature), pH, ammonia, or the amount of rainfall on or before the sampling date. In addition to reacting with ammonia nitrogen to form combined chlorine in the form of inorganic chloramines, chlorine also combines with various other nitrogenous compounds such as amino acids and proteinaceous matter (White, 1986). It is suspected that the differences observed in the February 16, 1988 cooling water samples relative to the samples from the other dates was due to an unusually higher abundance of nitrogenous compounds of unknown origin.

Because of the unpredictability of chlorine demand in the cooling water and the relatively long persistence of TRC on some occasions, it appears that a conservative use of chlorine coupled with dechlorination prior to discharge to the receiving stream will be important factors of environmental concern in the operation of the proposed K-Reactor cooling tower.

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APPENDICES

TABLE A-1

Residual Chlorine Levels in K-Reactor Cooling Water
Following a Variety of Chlorine Doses and Contact Periods on Several Dates

CHLORINE DOSE (mg/L)=0

DATE	CHLORINE DOSE (mg/L)	CONTACT PERIOD (min)	FRC (mg/L)	TRC (mg/L)
06MAY1986	0	0	0.04	0.03
06MAY1986	0	0	0.03	0.03
16MAY1986	0	0	0.04	0.04
16MAY1986	0	0	0.03	0.03
22MAY1986	0	0	0.02	0.02
22MAY1986	0	0	0.01	0.02
13OCT1986	0	0	0.02	0.04
13OCT1986	0	0	0.01	0.03
14OCT1986	0	0	0.02	0.04
14OCT1986	0	0	0.01	0.03
12JAN1987	0	0	0.02	0.02
12JAN1987	0	0	0.02	0.02
13JAN1987	0	0	0.03	0.02
13JAN1987	0	0	0.03	0.03
06APR1987	0	0	0.03	0.04
06APR1987	0	0	0.02	0.03
07APR1987	0	0	0.03	0.04
07APR1987	0	0	0.02	0.03
20JUL1987	0	0	0.00	0.00
20JUL1987	0	0	0.02	0.02
21JUL1987	0	0	0.02	0.04
21JUL1987	0	0	0.03	0.04
12OCT1987	0	0	0.02	0.00
12OCT1987	0	0	0.02	0.02
13OCT1987	0	0	0.02	0.02
13OCT1987	0	0	0.02	0.02
16FEB1988	0	0	0.02	0.02
16FEB1988	0	0	0.03	0.03
17FEB1988	0	0	0.02	0.03
17FEB1988	0	0	0.03	0.05

TABLE A-1

Residual Chlorine Levels in K-Reactor Cooling Water
Following a Variety of Chlorine Doses and Contact Periods on Several Dates

CHLORINE DOSE (mg/L)=1

DATE	CHLORINE DOSE (mg/L)	CONTACT PERIOD (min)	FRC (mg/L)	TRC (mg/L)
06MAY1986	1	1	0.08	0.50
06MAY1986	1	1	0.10	0.50
16MAY1986	1	1	0.35	0.48
16MAY1986	1	1	0.48	0.58
22MAY1986	1	1	0.21	0.70
22MAY1986	1	1	0.20	0.62
13OCT1986	1	1	0.08	0.49
13OCT1986	1	1	0.12	0.48
12JAN1987	1	1	0.11	0.60
12JAN1987	1	1	0.06	0.50
06APR1987	1	1	0.10	0.56
06APR1987	1	1	0.09	0.53
20JUL1987	1	1	0.05	0.32
20JUL1987	1	1	0.07	0.32
12OCT1987	1	1	0.22	0.37
12OCT1987	1	1	0.04	0.42
16FEB1988	1	1	0.02	0.17
16FEB1988	1	1	0.05	0.17
06MAY1986	1	10	0.08	0.45
06MAY1986	1	10	0.06	0.53
16MAY1986	1	10	0.22	0.48
16MAY1986	1	10	0.30	0.57
22MAY1986	1	10	0.07	0.62
22MAY1986	1	10	0.05	0.60
13OCT1986	1	10	0.05	0.42
13OCT1986	1	10	0.05	0.48
12JAN1987	1	10	0.18	0.58
12JAN1987	1	10	0.06	0.49
06APR1987	1	10	0.08	0.55
06APR1987	1	10	0.10	0.50
20JUL1987	1	10	0.05	0.30
20JUL1987	1	10	0.07	0.30
12OCT1987	1	10	0.07	0.37
12OCT1987	1	10	0.10	0.38
16FEB1988	1	10	0.02	0.12
16FEB1988	1	10	0.06	0.13
06MAY1986	1	30	0.08	0.45
06MAY1986	1	30	0.06	0.50
16MAY1986	1	30	0.05	0.47
16MAY1986	1	30	0.08	0.54
22MAY1986	1	30	0.06	0.63
22MAY1986	1	30	0.02	0.50
13OCT1986	1	30	0.08	0.45
13OCT1986	1	30	0.28	0.48
12JAN1987	1	30	0.04	0.49
12JAN1987	1	30	0.18	0.45
06APR1987	1	30	0.03	0.51
06APR1987	1	30	0.04	0.45
20JUL1987	1	30	0.02	0.26

TABLE A-1

Residual Chlorine Levels in K-Reactor Cooling Water
Following a Variety of Chlorine Doses and Contact Periods on Several Dates

CHLORINE DOSE (mg/L)=1

DATE	CHLORINE DOSE (mg/L)	CONTACT PERIOD (min)	FRC (mg/L)	TRC (mg/L)
20JUL1987	1	30	0.05	0.27
12OCT1987	1	30	0.05	0.33
12OCT1987	1	30	0.10	0.37
16FEB1988	1	30	0.01	0.12
16FEB1988	1	30	0.12	0.12
06MAY1986	1	60	0.07	0.45
06MAY1986	1	60	0.06	0.48
16MAY1986	1	60	0.04	0.42
16MAY1986	1	60	0.05	0.50
22MAY1986	1	60	0.06	0.58
22MAY1986	1	60	0.06	0.55
13OCT1986	1	60	0.04	0.42
13OCT1986	1	60	0.13	0.46
12JAN1987	1	60	0.15	0.47
12JAN1987	1	60	0.04	0.42
06APR1987	1	60	0.03	0.50
06APR1987	1	60	0.06	0.45
20JUL1987	1	60	0.02	0.22
20JUL1987	1	60	0.05	0.23
12OCT1987	1	60	0.10	0.30
12OCT1987	1	60	0.08	0.32
16FEB1988	1	60	0.02	0.12
16FEB1988	1	60	0.05	0.13
06MAY1986	1	120	0.04	0.40
06MAY1986	1	120	0.05	0.44
16MAY1986	1	120	0.08	0.38
16MAY1986	1	120	0.04	0.45
22MAY1986	1	120	0.08	0.57
22MAY1986	1	120	0.02	0.45
13OCT1986	1	120	0.05	0.38
13OCT1986	1	120	0.12	0.44
12JAN1987	1	120	0.06	0.40
12JAN1987	1	120	0.10	0.35
06APR1987	1	120	0.04	0.45
06APR1987	1	120	0.04	0.39
20JUL1987	1	120	0.02	0.20
20JUL1987	1	120	0.03	0.20
12OCT1987	1	120	0.06	0.28
12OCT1987	1	120	0.05	0.25
16FEB1988	1	120	0.02	0.10
16FEB1988	1	120	0.06	0.12
06MAY1986	1	240	0.04	0.38
06MAY1986	1	240	0.05	0.38
16MAY1986	1	240	0.08	0.33
16MAY1986	1	240	0.03	0.35
22MAY1986	1	240	0.05	0.48
22MAY1986	1	240	0.03	0.40
13OCT1986	1	240	0.06	0.29
13OCT1986	1	240	0.15	0.32

TABLE A-1

Residual Chlorine Levels in K-Reactor Cooling Water
Following a Variety of Chlorine Doses and Contact Periods on Several Dates

CHLORINE DOSE (mg/L)=1

DATE	CHLORINE DOSE (mg/L)	CONTACT PERIOD (min)	FRC (mg/L)	TRC (mg/L)
12JAN1987	1	240	0.05	0.28
12JAN1987	1	240	0.09	0.34
06APR1987	1	240	0.03	0.38
06APR1987	1	240	0.05	0.42
20JUL1987	1	240	0.03	0.15
20JUL1987	1	240	0.04	0.15
12OCT1987	1	240	0.05	0.23
12OCT1987	1	240	0.07	0.23
16FEB1988	1	240	0.03	0.07
16FEB1988	1	240	0.06	0.07
16MAY1986	1	1440	0.05	0.13
16MAY1986	1	1440	0.05	0.16
22MAY1986	1	1440	0.07	0.22
22MAY1986	1	1440	0.09	0.20
13OCT1986	1	1440	0.02	0.06
13OCT1986	1	1440	0.03	0.06
12JAN1987	1	1440	0.01	0.07
12JAN1987	1	1440	0.02	0.04
06APR1987	1	1440	0.12	0.19
06APR1987	1	1440	0.08	0.15
20JUL1987	1	1440	0.01	0.03
20JUL1987	1	1440	0.03	0.04
12OCT1987	1	1440	0.04	0.07
12OCT1987	1	1440	0.02	0.06
16FEB1988	1	1440	0.02	0.02
16FEB1988	1	1440	0.04	0.04
06MAY1986	1	2100	0.05	0.15
06MAY1986	1	2100	0.05	0.23

TABLE A-1

Residual Chlorine Levels in K-Reactor Cooling Water
Following a Variety of Chlorine Doses and Contact Periods on Several Dates

CHLORINE DOSE (mg/L)=3

DATE	CHLORINE DOSE (mg/L)	CONTACT PERIOD (min)	FRC (mg/L)	TRC (mg/L)
06MAY1986	3	1	0.90	1.70
06MAY1986	3	1	1.20	1.90
16MAY1986	3	1	1.11	1.90
16MAY1986	3	1	1.11	1.85
22MAY1986	3	1	1.10	2.00
22MAY1986	3	1	1.00	1.90
13OCT1986	3	1	0.49	1.58
13OCT1986	3	1	1.10	1.39
14OCT1986	3	1	0.65	1.60
14OCT1986	3	1	0.35	1.20
14OCT1986	3	1	0.06	1.50
12JAN1987	3	1	0.45	1.45
12JAN1987	3	1	0.50	1.79
13JAN1987	3	1	0.60	1.60
13JAN1987	3	1	0.40	1.40
13JAN1987	3	1	0.55	1.60
05APR1987	3	1	0.82	1.80
06APR1987	3	1	1.00	1.70
07APR1987	3	1	0.95	1.95
07APR1987	3	1	0.90	1.80
07APR1987	3	1	1.20	2.00
20JUL1987	3	1	0.88	1.40
20JUL1987	3	1	1.10	1.40
21JUL1987	3	1	1.00	1.50
21JUL1987	3	1	1.10	1.58
21JUL1987	3	1	1.20	1.48
21JUL1987	3	1	1.18	1.60
21JUL1987	3	1	1.30	1.78
12OCT1987	3	1	0.85	1.40
12OCT1987	3	1	0.78	1.40
13OCT1987	3	1	1.00	1.50
13OCT1987	3	1	1.20	1.20
13OCT1987	3	1	1.10	1.50
16FEB1988	3	1	0.03	0.80
16FEB1988	3	1	0.09	0.69
17FEB1988	3	1	0.22	1.10
17FEB1988	3	1	0.70	1.30
17FEB1988	3	1	0.15	0.95
06MAY1986	3	10	.	1.20
06MAY1986	3	10	.	1.30
16MAY1986	3	10	0.27	1.05
16MAY1986	3	10	0.48	1.08
22MAY1986	3	10	0.42	1.10
22MAY1986	3	10	0.35	1.00
13OCT1986	3	10	0.20	0.96
13OCT1986	3	10	0.35	0.10
14OCT1986	3	10	0.30	1.00
14OCT1986	3	10	0.17	1.04
14OCT1986	3	10	0.02	0.90

TABLE A-1

Residual Chlorine Levels in K-Reactor Cooling Water
Following a Variety of Chlorine Doses and Contact Periods on Several Dates

CHLORINE DOSE (mg/L)=3

DATE	CHLORINE DOSE (mg/L)	CONTACT PERIOD (min)	FRC (mg/L)	TRC (mg/L)
12JAN1987	3	10	0.65	1.00
12JAN1987	3	10	0.38	1.00
06APR1987	3	10	0.28	1.10
06APR1987	3	10	0.16	1.10
07APR1987	3	10	0.30	0.90
07APR1987	3	10	0.22	0.97
07APR1987	3	10	0.29	0.90
20JUL1987	3	10	0.42	0.83
20JUL1987	3	10	0.60	0.90
21JUL1987	3	10	0.75	1.10
21JUL1987	3	10	0.55	0.91
21JUL1987	3	10	0.55	0.88
120CT1987	3	10	0.48	0.88
120CT1987	3	10	0.44	0.85
130CT1987	3	10	0.53	0.80
130CT1987	3	10	0.42	0.75
130CT1987	3	10	0.65	0.95
16FEB1988	3	10	0.02	0.71
16FEB1988	3	10	0.18	0.69
17FEB1988	3	10	0.18	0.89
17FEB1988	3	10	0.08	0.85
17FEB1988	3	10	0.15	0.90
06MAY1986	3	30	0.10	0.59
06MAY1986	3	30	0.28	0.69
16MAY1986	3	30	0.20	0.58
16MAY1986	3	30	0.28	0.64
22MAY1986	3	30	0.17	0.62
22MAY1986	3	30	0.05	0.50
130CT1986	3	30	0.08	0.92
130CT1986	3	30	0.15	0.88
140CT1986	3	30	0.18	0.75
140CT1986	3	30	0.06	0.70
140CT1986	3	30	0.08	0.70
12JAN1987	3	30	0.12	0.99
12JAN1987	3	30	0.08	0.85
06APR1987	3	30	0.16	0.94
06APR1987	3	30	0.35	1.30
07APR1987	3	30	0.12	0.70
07APR1987	3	30	0.08	0.70
07APR1987	3	30	0.12	0.50
20JUL1987	3	30	0.15	0.45
20JUL1987	3	30	0.15	0.53
21JUL1987	3	30	0.20	0.45
21JUL1987	3	30	0.06	0.41
21JUL1987	3	30	0.31	0.51
120CT1987	3	30	0.15	0.48
120CT1987	3	30	0.12	0.45
130CT1987	3	30	0.22	0.48
130CT1987	3	30	0.22	0.47

TABLE A-1

Residual Chlorine Levels in K-Reactor Cooling Water
Following a Variety of Chlorine Doses and Contact Periods on Several Dates

CHLORINE DOSE (mg/L)=3

DATE	CHLORINE DOSE (mg/L)	CONTACT PERIOD (min)	FRC (mg/L)	TRC (mg/L)
13OCT1987	3	30	0.20	0.42
16FEB1988	3	30	0.03	0.70
16FEB1988	3	30	0.10	0.65
17FEB1988	3	30	0.03	0.78
17FEB1988	3	30	0.18	0.82
17FEB1988	3	30	0.04	0.82
06MAY1986	3	60	0.06	0.39
06MAY1986	3	60	0.08	0.45
16MAY1986	3	60	0.08	0.41
16MAY1986	3	60	0.04	0.39
22MAY1986	3	60	0.08	0.46
22MAY1986	3	60	0.03	0.45
13OCT1986	3	60	0.07	0.75
13OCT1986	3	60	0.58	0.85
12JAN1987	3	60	0.12	0.87
12JAN1987	3	60	0.01	0.82
06APR1987	3	60	0.13	0.80
06APR1987	3	60	0.05	0.80
20JUL1987	3	60	0.08	0.32
20JUL1987	3	60	0.09	0.34
12OCT1987	3	60	0.10	0.35
12OCT1987	3	60	0.12	0.34
16FEB1988	3	60	0.07	0.69
16FEB1988	3	60	0.12	0.63
06MAY1986	3	120	0.06	0.30
06MAY1986	3	120	0.05	0.30
16MAY1986	3	120	0.08	0.32
16MAY1986	3	120	0.08	0.36
22MAY1986	3	120	0.08	0.40
22MAY1986	3	120	0.03	0.40
13OCT1986	3	120	0.10	0.72
13OCT1986	3	120	0.23	0.75
12JAN1987	3	120	0.15	0.69
12JAN1987	3	120	0.01	0.69
06APR1987	3	120	0.07	0.75
06APR1987	3	120	0.17	0.79
20JUL1987	3	120	0.05	0.25
20JUL1987	3	120	0.05	0.22
12OCT1987	3	120	0.03	0.25
12OCT1987	3	120	0.05	0.23
16FEB1988	3	120	0.02	0.60
16FEB1988	3	120	0.04	0.59
06MAY1986	3	240	0.04	0.24
06MAY1986	3	240	0.05	0.24
16MAY1986	3	240	0.06	0.23
16MAY1986	3	240	0.07	0.19
22MAY1986	3	240	0.07	0.29
22MAY1986	3	240	0.02	0.32
13OCT1986	3	240	0.06	0.58

TABLE A-1

Residual Chlorine Levels in K-Reactor Cooling Water
Following a Variety of Chlorine Doses and Contact Periods on Several Dates

CHLORINE DOSE (mg/L)=3

DATE	CHLORINE DOSE (mg/L)	CONTACT PERIOD (min)	FRC (mg/L)	TRC (mg/L)
13OCT1986	3	240	0.06	0.60
12JAN1987	3	240	0.44	0.58
12JAN1987	3	240	0.08	0.58
06APR1987	3	240	0.07	0.56
06APR1987	3	240	0.06	0.61
20JUL1987	3	240	0.05	0.15
20JUL1987	3	240	0.04	0.15
12OCT1987	3	240	0.05	0.20
12OCT1987	3	240	0.05	0.16
16FEB1988	3	240	0.06	0.50
16FEB1988	3	240	0.11	0.50
16MAY1986	3	1440	0.01	0.05
16MAY1986	3	1440	0.02	0.02
22MAY1986	3	1440	0.05	0.15
22MAY1986	3	1440	0.05	0.15
13OCT1986	3	1440	0.04	0.22
13OCT1986	3	1440	0.09	0.25
12JAN1987	3	1440	0.35	0.48
12JAN1987	3	1440	0.05	0.25
06APR1987	3	1440	0.05	0.29
06APR1987	3	1440	0.05	0.28
20JUL1987	3	1440	0.03	0.06
20JUL1987	3	1440	0.02	0.03
12OCT1987	3	1440	0.02	0.04
12OCT1987	3	1440	0.01	0.05
16FEB1988	3	1440	0.02	0.18
16FEB1988	3	1440	0.04	0.22
06MAY1986	3	2100	0.01	0.12
06MAY1986	3	2100	0.05	0.12

TABLE A-1

Residual Chlorine Levels in K-Reactor Cooling Water
Following a Variety of Chlorine Doses and Contact Periods on Several Dates

CHLORINE DOSE (mg/L)=4

DATE	CHLORINE DOSE (mg/L)	CONTACT PERIOD (min)	FRC (mg/L)	TRC (mg/L)
06MAY1986	4	1	1.40	2.00
06MAY1986	4	1	1.43	2.20
22MAY1986	4	1	1.80	2.50
22MAY1986	4	1	1.50	2.50
06MAY1986	4	10	1.00	1.40
06MAY1986	4	10	1.10	1.70
22MAY1986	4	10	1.18	1.80
22MAY1986	4	10	1.10	1.55
06MAY1986	4	30	0.65	0.85
06MAY1986	4	30	0.65	1.00
22MAY1986	4	30	0.65	1.00
22MAY1986	4	30	0.60	0.85
06MAY1986	4	60	0.27	0.50
06MAY1986	4	60	0.35	0.65
22MAY1986	4	60	0.44	0.65
22MAY1986	4	60	0.30	0.55
06MAY1986	4	120	0.12	0.28
06MAY1986	4	120	0.17	0.41
22MAY1986	4	120	0.22	0.40
22MAY1986	4	120	0.10	0.30
06MAY1986	4	240	0.05	0.15
06MAY1986	4	240	0.07	0.22
22MAY1986	4	240	0.05	0.20
22MAY1986	4	240	0.02	0.20
06MAY1986	4	2100	0.01	0.03
06MAY1986	4	2100	0.05	0.09

TABLE A-1

Residual Chlorine Levels in K-Reactor Cooling Water
Following a Variety of Chlorine Doses and Contact Periods on Several Dates

CHLORINE DOSE (mg/L)=5

DATE	CHLORINE DOSE (mg/L)	CONTACT PERIOD (min)	FRC (mg/L)	TRC (mg/L)
16MAY1986	5	1	3.40	3.60
16MAY1986	5	1	2.40	2.75
13OCT1986	5	1	1.60	2.30
13OCT1986	5	1	2.00	2.50
12JAN1987	5	1	2.25	3.10
12JAN1987	5	1	2.60	3.20
06APR1987	5	1	2.00	2.80
06APR1987	5	1	1.80	2.50
20JUL1987	5	1	2.20	2.50
20JUL1987	5	1	2.20	2.50
12OCT1987	5	1	2.20	2.45
12OCT1987	5	1	1.90	2.40
16FEB1988	5	1	0.23	1.38
16FEB1988	5	1	0.20	1.10
16MAY1986	5	10	2.40	2.70
16MAY1986	5	10	2.00	2.45
13OCT1986	5	10	0.25	0.79
13OCT1986	5	10	1.30	1.80
12JAN1987	5	10	1.30	1.75
12JAN1987	5	10	1.30	1.80
06APR1987	5	10	1.50	2.00
06APR1987	5	10	1.20	1.80
20JUL1987	5	10	1.80	2.20
20JUL1987	5	10	1.90	2.20
12OCT1987	5	10	1.50	1.80
12OCT1987	5	10	1.40	1.70
16FEB1988	5	10	0.03	1.00
16FEB1988	5	10	0.25	0.95
16MAY1986	5	30	2.10	2.25
16MAY1986	5	30	1.90	2.25
13OCT1986	5	30	0.58	0.80
13OCT1986	5	30	0.58	0.99
12JAN1987	5	30	1.10	1.40
12JAN1987	5	30	1.00	1.30
06APR1987	5	30	1.00	1.35
06APR1987	5	30	0.82	1.20
20JUL1987	5	30	1.40	1.70
20JUL1987	5	30	1.40	1.60
12OCT1987	5	30	1.20	1.50
12OCT1987	5	30	1.08	1.40
16FEB1988	5	30	0.03	0.95
16FEB1988	5	30	0.15	0.85
16MAY1986	5	60	1.64	2.01
16MAY1986	5	60	1.62	1.90
13OCT1986	5	60	0.25	0.48
13OCT1986	5	60	0.35	0.53
12JAN1987	5	60	0.78	1.10
12JAN1987	5	60	0.50	0.92
06APR1987	5	60	0.72	0.95

TABLE A-1

Residual Chlorine Levels in K-Reactor Cooling Water
Following a Variety of Chlorine Doses and Contact Periods on Several Dates

CHLORINE DOSE (mg/L)=5

DATE	CHLORINE DOSE (mg/L)	CONTACT PERIOD (min)	FRC (mg/L)	TRC (mg/L)
06APR1987	5	60	0.52	0.80
20JUL1987	5	60	1.00	1.40
20JUL1987	5	60	1.08	1.30
12OCT1987	5	60	0.95	1.15
12OCT1987	5	60	0.85	1.10
16FEB1988	5	60	0.22	0.92
16FEB1988	5	60	0.08	0.79
16MAY1986	5	120	1.35	1.70
16MAY1986	5	120	1.30	1.60
13OCT1986	5	120	0.06	0.29
13OCT1986	5	120	0.13	0.30
12JAN1987	5	120	0.42	0.65
12JAN1987	5	120	0.30	0.50
06APR1987	5	120	0.38	0.58
06APR1987	5	120	0.24	0.46
20JUL1987	5	120	0.68	1.00
20JUL1987	5	120	0.68	0.87
12OCT1987	5	120	0.60	0.82
12OCT1987	5	120	0.55	0.73
16FEB1988	5	120	0.02	0.78
16FEB1988	5	120	0.15	0.70
16MAY1986	5	240	0.78	1.10
16MAY1986	5	240	0.70	1.00
13OCT1986	5	240	0.05	0.13
13OCT1986	5	240	0.05	0.18
12JAN1987	5	240	0.12	0.28
12JAN1987	5	240	0.08	0.22
06APR1987	5	240	0.05	0.26
06APR1987	5	240	0.03	0.19
20JUL1987	5	240	0.30	0.51
20JUL1987	5	240	0.29	0.48
12OCT1987	5	240	0.35	0.58
12OCT1987	5	240	0.28	0.48
16FEB1988	5	240	0.03	0.70
16FEB1988	5	240	0.08	0.65
16MAY1986	5	1440	0.05	0.07
16MAY1986	5	1440	0.05	0.10
13OCT1986	5	1440	0.05	0.05
13OCT1986	5	1440	0.05	0.05
12JAN1987	5	1440	0.00	0.05
12JAN1987	5	1440	0.04	0.05
06APR1987	5	1440	0.04	0.12
06APR1987	5	1440	0.02	0.07
20JUL1987	5	1440	0.04	0.09
20JUL1987	5	1440	0.04	0.10
12OCT1987	5	1440	0.03	0.08
12OCT1987	5	1440	0.03	0.05
16FEB1988	5	1440	0.08	0.30
16FEB1988	5	1440	0.04	0.35

TABLE A-2

Temperature, NH4-N, and pH Measurements of K-Reactor Cooling Water Collected on Seven Dates

DATE	TEMP	NH4_N	pH
16MAY1986	69.0	0.34	7.8
16MAY1986	.	0.35	7.8
13OCT1986	67.0	0.65	7.6
13OCT1986	.	0.65	7.6
12JAN1987	9.5	0.65	7.0
12JAN1987	.	0.65	7.1
06APR1987	45.0	0.60	7.5
06APR1987	.	0.60	7.5
20JUL1986	49.0	0.32	7.1
20JUL1986	.	0.33	7.3
12OCT1987	45.0	0.29	7.3
12OCT1987	.	0.27	7.3
16FEB1988	40.0	0.58	7.5
16FEB1988	.	0.62	7.6